Space and Electronics Group
One Space Park
Redondo Beach, CA 90278

Hyperion Imaging Spectrometer on the New Millennium Program Earth Orbiter-1 System

Authors:
Jay Pearlman, Stephen Carman, Paul Lee,
Lushalan Liao, and Carol Segal

November 1999
Hyp_00-600.002

1.0 Introduction

The EO-1 mission is focused on new sensor and spacecraft technologies, which can directly reduce the cost of Landsat and related Earth Monitoring Systems.

The EO-1 satellite will be in an orbit that covers the same ground track as Landsat 7, approximately one minute later. Following EO-1, in nearly the same orbit, are SAC-C (an Argentinian satellite) and TERRA. This will enable EO-1 to obtain images of the same ground areas at nearly the same time, so that direct comparison of results can be obtained for Landsat-ETM+ and the three primary E0-1 instruments. The three primary instruments are the Advanced Land Imager (ALI), the Hyperion and the Linear etalon imaging spectrometer array Atmospheric Corrector (LAC). An overview of the operations scenario for these three instruments is given in Figure 1-1.

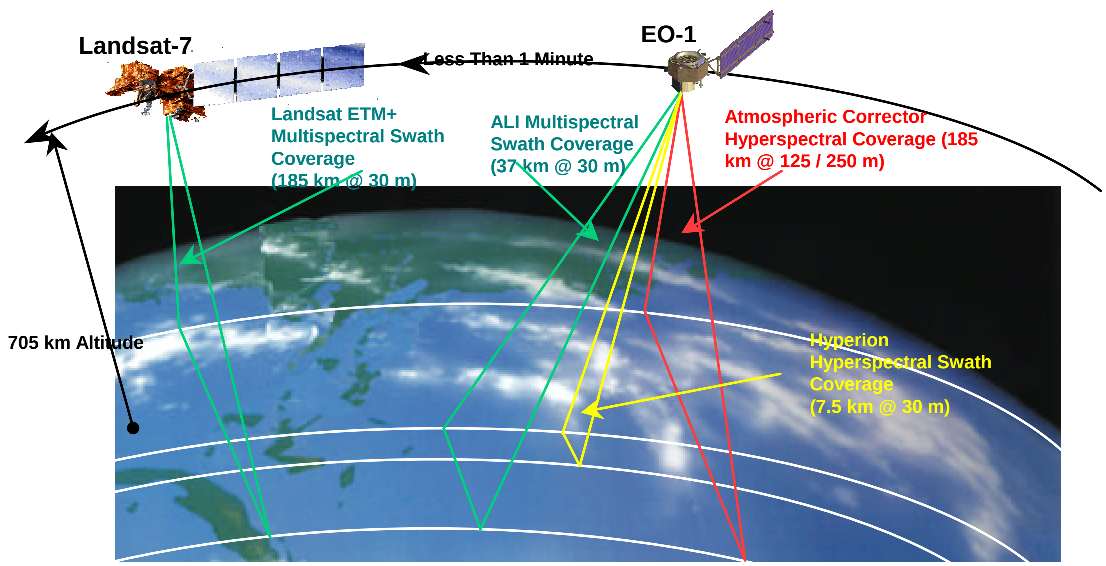


Figure 1-1– A view of the Earth with EO-1 above showing instrument swath widths

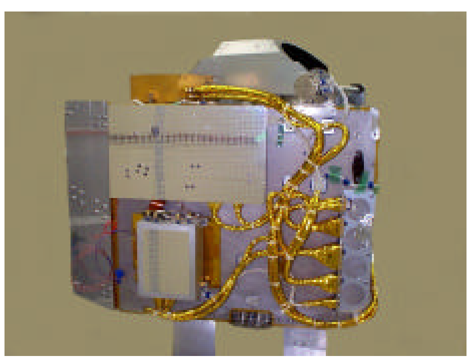
A summary of the three instrument characteristics is given in Figure 1-2. ALI is a calibrated, multi-spectral system consisting of a 15° Wide Field Telescope (WFT) and partially populated focal plane, occupying 1/5th of the field-of-view. This gives a ground swath width of 37km. Hyperion is a grating imaging spectrometer having a 30-meter ground sample distance over a 7.5 kilometer swath and providing 10nm (sampling interval) contiguous bands of the solar reflected spectrum from 400-2500nm. LAC is an imaging spectrometer designed to monitor the atmospheric water absorption lines for correction of atmospheric effects in multispectral imagers such as ETM+ on Landsat. This paper focuses on the Hyperion Instrument.

Parameters	MULTISPECTRAL	HYPERSPECTRAL	
	ALI	HYPERION	LAC
Spectral Range	0.4 - 2.4 µm	0.4 - 2.5 µm	0.9 - 1.6 µm
Spatial Resolution	30 m	30 m	250 m
Swath Width	37 Km	7.5 Km	185 Km
Spectral Resolution	Variable	10 nm	2-6 nm
Spectral Coverage	Discrete	Continuous	Continuous
Pan Band Resolution	10 m	N/A	N/A
Number of Bands	10	220	256

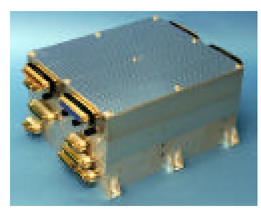
Figure 1-2 – Summary Of Primary EO-1 Instrument Characteristics.

2.0 Hyperion System Description

The Hyperion instrument provides high quality calibrated data that can support evaluation of hyperspectral technology for Earth observing missions. The Hyperion is a push broom instrument. Each image taken in this "push broom" configuration captures the spectrum of a line 30m long by 7.5Km wide (perpendicular to the satellite motion). Hyperion has a single telescope and two spectrometers, one visible/near infrared (VNIR) spectrometer and one short-wave infrared (SWIR)) spectrometer. The Hyperion instrument consists of three physical units (Figure 2-1): (a) the Hyperion Sensor Assembly (HSA); (b) the Hyperion Electronics Assembly (HEA); and (c) Cryocooler Electronics Assembly (CEA). The HSA includes the optical systems, cryocooler, in-flight calibration system and the high-speed focal plane electronics. The HEA contains the interface and control electronics for the instrument and the CEA controls cryocooler operation. These units are placed on the deck of the spacecraft with the viewing direction along the major axes of the spacecraft. (See Figure 2-2)



HSA



CEA

HEA

Figure 2-1 – The Hyperion Instrument

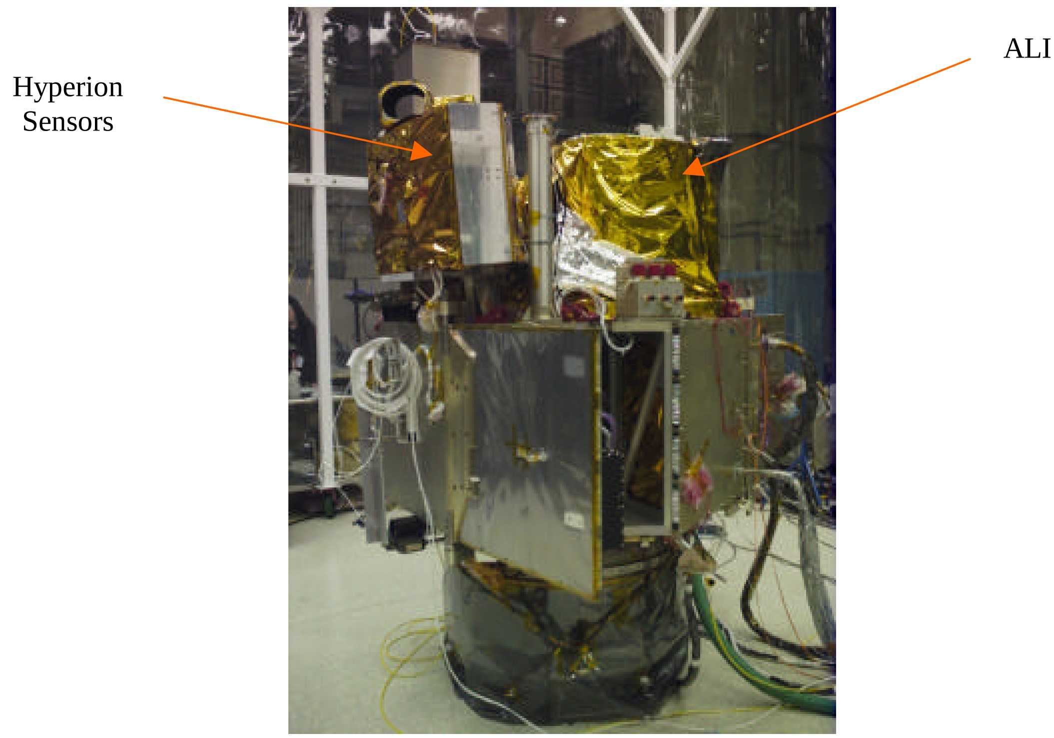


Figure 2-2 – EO-1 Spacecraft with sensors mounted on the nadir deck.

The Hyperion Sensor Assembly (HSA) includes the telescope, the two grating spectrometers and the supporting focal plane electronics and cooling system (See Figure 2-3). The Hyperion telescope (fore-optics) is a three-mirror astigmate design. All of the mirrors in the system along with the structure holding the optical elements are constructed from aluminum so that the mirrors and housing all expand and contract at the same rates. This results in an athermal design over a limited temperature range. In operation, the housing will be maintained at $20^0 \pm 2^0$C for precision imaging and alignment.

The Hyperion telescope images the Earth onto a slit that defines the instantaneous field-of-view which is 0.624^0 wide (i.e., 7.5 Km swath width from a 705 Km altitude) by 42.55 μ radians (30 meters) in the satellite velocity direction. This slit image of the Earth is relayed at a magnification of 1.38:1 to two focal planes in the two grating imaging spectrometers. A dichroic filter in the system reflects the band from 400 to 1,000nm to one-spectrometer and transmits the band from 900 to 2,500nm to the other spectrometer. . The SWIR overlap with the VNIR from 900 to 1000nm will allow cross calibration between the two spectrometers. Both spectrometers use a 3-reflector Offner optical configuration with JPL convex grating.

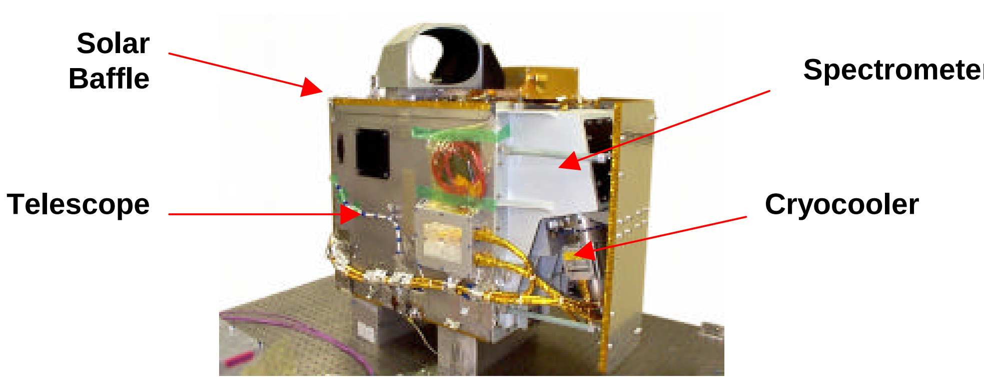


Figure 2-3 – Hyperion Sensor Assembly (HSA)

The visible/near-infrared (VNIR) spectrometer has an array of 60µm pixels created by aggregating 3x3 sub-arrays of a 20µm CCD detector array. The VNIR spectrometer uses a 60 (spectral) by 250 (spatial) pixel array, which provides a 10nm spectral bandwidth over a range of 400-1000nm. The short wave infrared (SWIR) spectrometer has 60µm, HgCdTe detectors in an array of 160 (spectral) x 250 (spatial) channels. Similar to the VNIR, the SWIR spectral bandwidth is 10nm. Thus, the spectral range of the instrument extends from 400 to 2,500nm with a spectral resolution of 10nm. The HgCdTe detectors in the SWIR spectrometer are cooled by an advanced TRW cryocooler and are maintained at 110 K during data collections.

A common calibration system is provided for both the VNIR and SWIR spectrometers. Dual calibration lamps produce reference signals to monitor detector performance following image acquisition. This internal calibration is cross-referenced against both solar and lunar calibrations. The solar calibration utilizes a diffuse reflector on the backside of the optical cover to provide uniform illumination across the focal plane arrays. The cover is set at a 37-degree angle and the spacecraft is oriented such that the sun enters the solar baffle normal to the earth viewing direction. Solar and in-flight calibration data will be used as the primary source for monitoring radiometric stability, with ground site (vicarious) and lunar imaging treated as secondary calibration data.

As noted above, the HSA is interfaced with two electronics boxes, the Hyperion Electronics Assembly (HEA) and the Cryocooler Electronics Assembly (CEA).

The HEA has six electronic boards for control and data formatting (See Figure 2-4). These include: a formatter board for timing synchronization with image data reformatting, a processor board that controls instrument operations, a telemetry board for receipt and conditioning of housekeeping data, a transceiver board for interface with the spacecraft computer, and boards for power and motor/lamps drives.

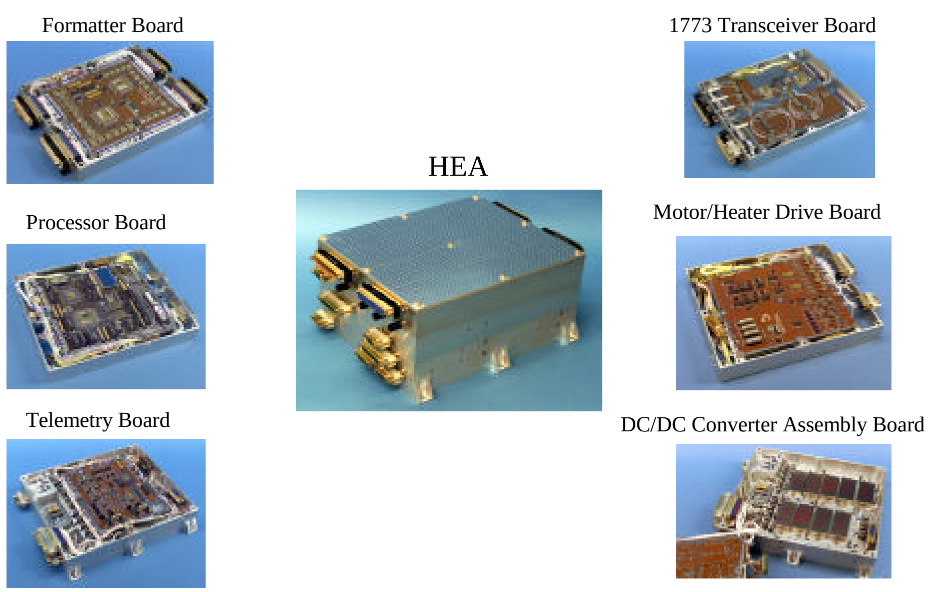


Figure 2-4 – HEA with various boards

The Hyperion cryocooler system consists of a Mechanical Pulse Tube (MPT) cooler with accelerometer electronics, Control Electronics Assembly (CEA), and LVDT electronics. The cooler provides focal plane cooling via a thermal strap connected to the cold block of the cooler. The cooler rejects heat to a radiator panel. The mechanical cooler (as shown in Figure 2-5) includes a compressor, which flexure springs support a moving-coil linear motor, which drives the compressor pistons. A balancer vibrationally cancels the force that this piston motion creates. LVDT sensors are used to measure the piston position and the balancer position, control the piston strokes and reduce vibration. An accelerometer, mounted on the outside of the compressor housing, provides the feedback responses for the vibration control algorithm in the drive electronics (CEA). The CEA contains three slice subassemblies, one for control (control slice), one for power conversion (conversion slice), and one for power amplifiers (power slice).

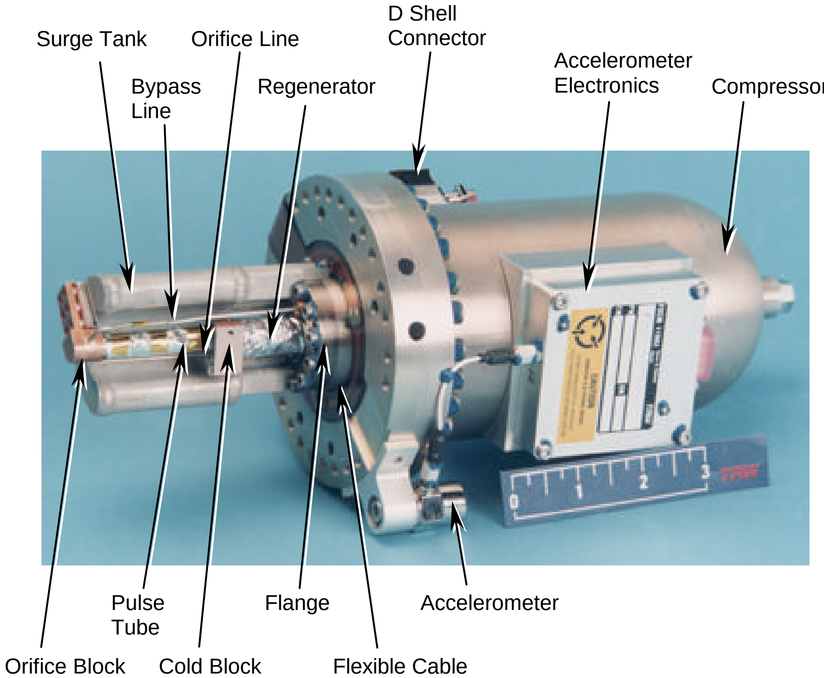


Figure 2-5 – Hyperion Cryocooler

3.0 Hyperion Performance and Characterization

The instrument was extensively characterized in the laboratory to provide a baseline for in-flight performance assessment. A majority of the testing was done with Hyperion in a thermal vacuum chamber (see Figure 3-1). A calibration system was interfaced with the instrument. The system consists of a monochrometer whose output is used in one of two optical configurations (See Figure 3-2). Either the light illuminates a pinhole, slit or knife edge which is at the focus of an off-axis parabola reflector or the light illuminates a spectralon panel whose reflection is collimated by the same off-axis parabola. Figure 3-2 also shows a radiometer that is used as a transfer standard for absolute and NIST traceable sources/detectors. Typically, the light from the steering mirror is directed onto the transfer radiometer, or (when the radiometer is removed), into the Hyperion aperture through a vacuum chamber window.

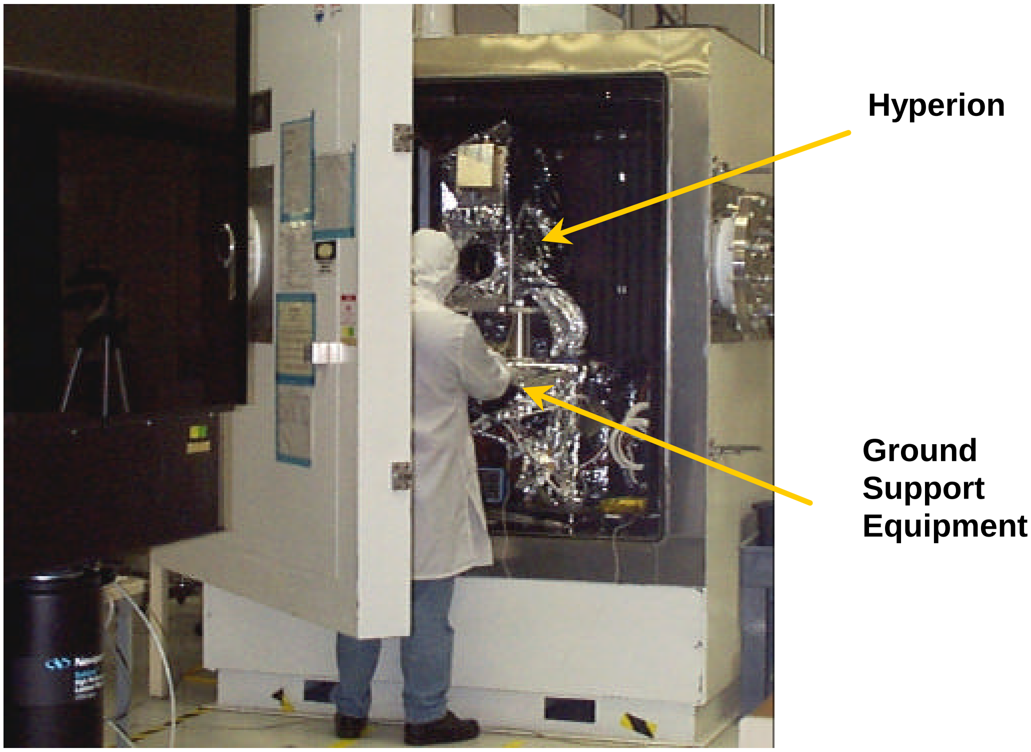


Figure 3-1 Hyperion in Vacuum Chamber

The instrument characterization included radiometric calibration and an image quality assessment. A preliminary data set is presented here (MTF, spectral response and signal to noise). The full characterization will be presented upon completion of the analysis in the near future. The MTF was measured in two ways, using a knife edge technique and using a slit technique. In the former, the image of an illuminated knife-edge is scanned across the focal plane and the instrument response is measured (see Figure 3-3). The derivative of the knife edge data gives the point spread function (PSF) and the Fourier transform of the PSF is the modulation transfer function (MTF). The results of this measurement show the MTF ranges between 0.24 and 0.28 as given in the table of Figure 3-3.

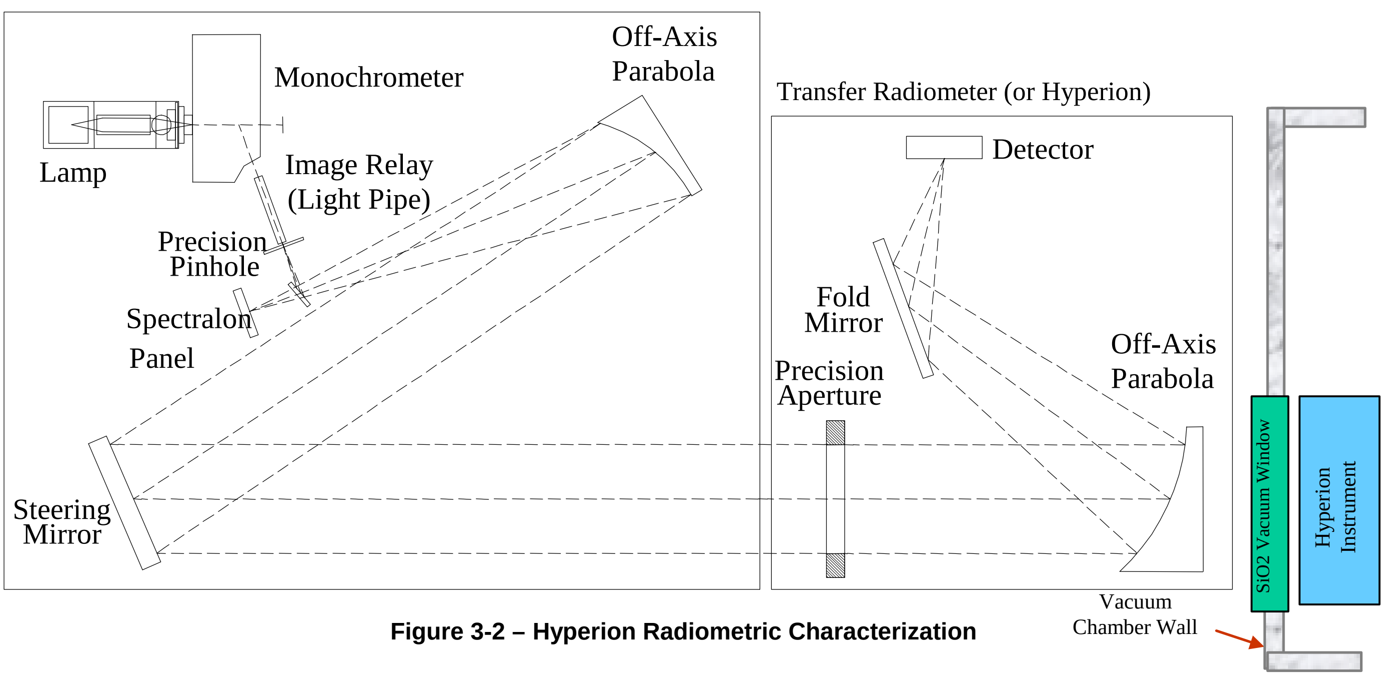
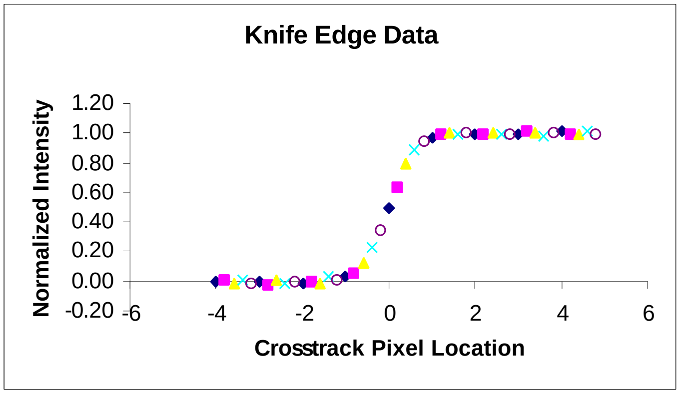
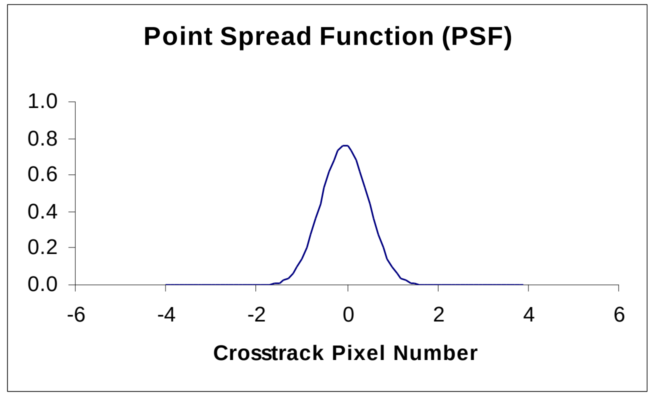


Figure 3-2 – Hyperion Radiometric Characterization

The spectral response was characterized to determine band centers and bandwidths. This was done by scanning narrow-band monochrometer light across the focal plane. A summary of the results is given in the tables of Figure 3-4 and Figure 3-5 for the VNIR and SWIR focal planes respectively.





Measured Average Along-Track MTF Values						
500 nm	630 nm	900 nm	1050 nm	1250 nm	1650 nm	2200 nm
0.26	0.26	0.24	0.28	0.28	0.26	0.26

Figure 3-3 – The measured MTF of Hyperion for selected wavelengths

VNIR Channel Center Wavelengths (nm, accuracy +/- 0.5nm)					
Spectral Channel / FOV #	13	31	40	48	57
6	477.4	656.5	753.6	834.3	925.4
71	478.5	657.5	754.1	834.9	925.1
136	478.0	656.8	753.7	834.4	925.3
196	476.8	655.7	752.8	833.4	924.4
251	475.1	654.6	751.3	831.9	922.8

VNIR FWHM of Spectral Response Functions (nm)					
Spectral Channel / FOV #	13	31	40	48	57
6	11.2	10.5	10.6	11.1	11.1
71	11.6	10.4	10.9	11.3	11.3
136	11.3	10.3	10.7	11.3	11.3
196	11.4	10.2	10.7	11.4	11.3
251	11.3	10.2	10.6	11.3	11.2

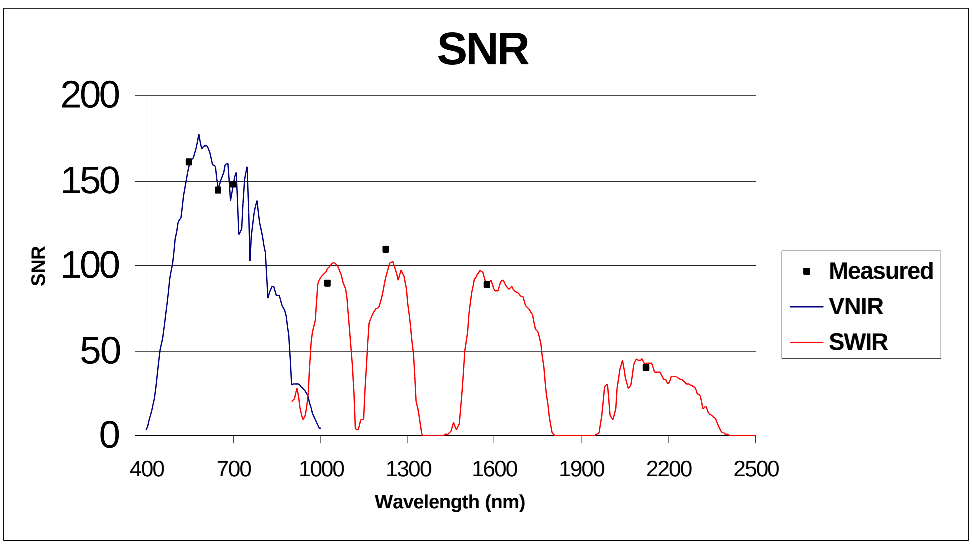
Figure 3-4 – The spectral response functions for visible and near infrared wavelengths.

SWIR Channel Center Wavelengths (nm +/- 0.5nm)					
Spectral Channel / FOV #	27	57	87	126	156
6	2314.1	2012.2	1711.2	1314.3	1013.3
71	2314.2	2012.1	1711.4	1315.2	1013.2
136	2314.0	2012.2	1711.6	1315.1	1013.2
196	2313.9	2012.1	1711.6	1315.1	1013.2
251	2313.7		1711.1	1314.2	1012.9

SWIR FWHM of Spectral Response Function					
Spectral Channel / FOV #	27	57	87	126	156
6	10.4	10.6	11.6	10.6	10.7
71	10.5	10.8	11.4	10.6	11.1
136	10.4	10.9	11.8	10.8	11.2
196	10.5	11.1	11.6	10.8	11.2
251	10.2		11.3	10.6	11.1

Figure 3-5 – The spectral response functions for shortwave infrared wavelengths.

The signal-to-noise properties of Hyperion were determined by combining the measured spectral response function with a baseline model of observation conditions. The baseline conditions assumed a 60° Solar Zenith Angle and a 30% uniform Albedo. The resulting signal to noise performances is shown in Figure 3-6. The values shown by squares in the figure are the measured values during Hyperion characterization. The continuous curve is a model fit using the baseline conditions.



Hyperion Measured SNR						
550 nm	650 nm	700 nm	1025 nm	1225 nm	1575 nm	2125 nm
161	144	147	90	110	89	40

Figure 3-6 – Signal to Noise characteristics of the Hyperion Instrument.

4.0 Hyperion Data Processing

Data from Hyperion is stored on-board the spacecraft in a "WARP" solid-state recorder. The data is downlinked and transmitted to GSFC for Level 0 processing. This processing includes removal of transmission artifacts and reordering of the data formats. The VNIR and SWIR data files are combined to provide a single image file ("raw imagery"). This and the flight data (housekeeping data) and ancillary data form a complete Level 0 data set. (See Figure 4-1) The data is transmitted to TRW for assessment and Level 1 radiometric calibration. Radiometric calibration formats the image and applies a radiometric calibration based on coefficients derived from both laboratory and on-orbit calibration data. The ancillary data is converted into engineering units to facilitate their later use. The different data types (image, metadata and ancillary data) are then combined into a standard data set and subject to a quality analysis. The data in the form of "cubes", whose images cover 20km along track and 7.5km across track, are put into HDF format and transmitted to NASA GSFC for archiving during the mission life.

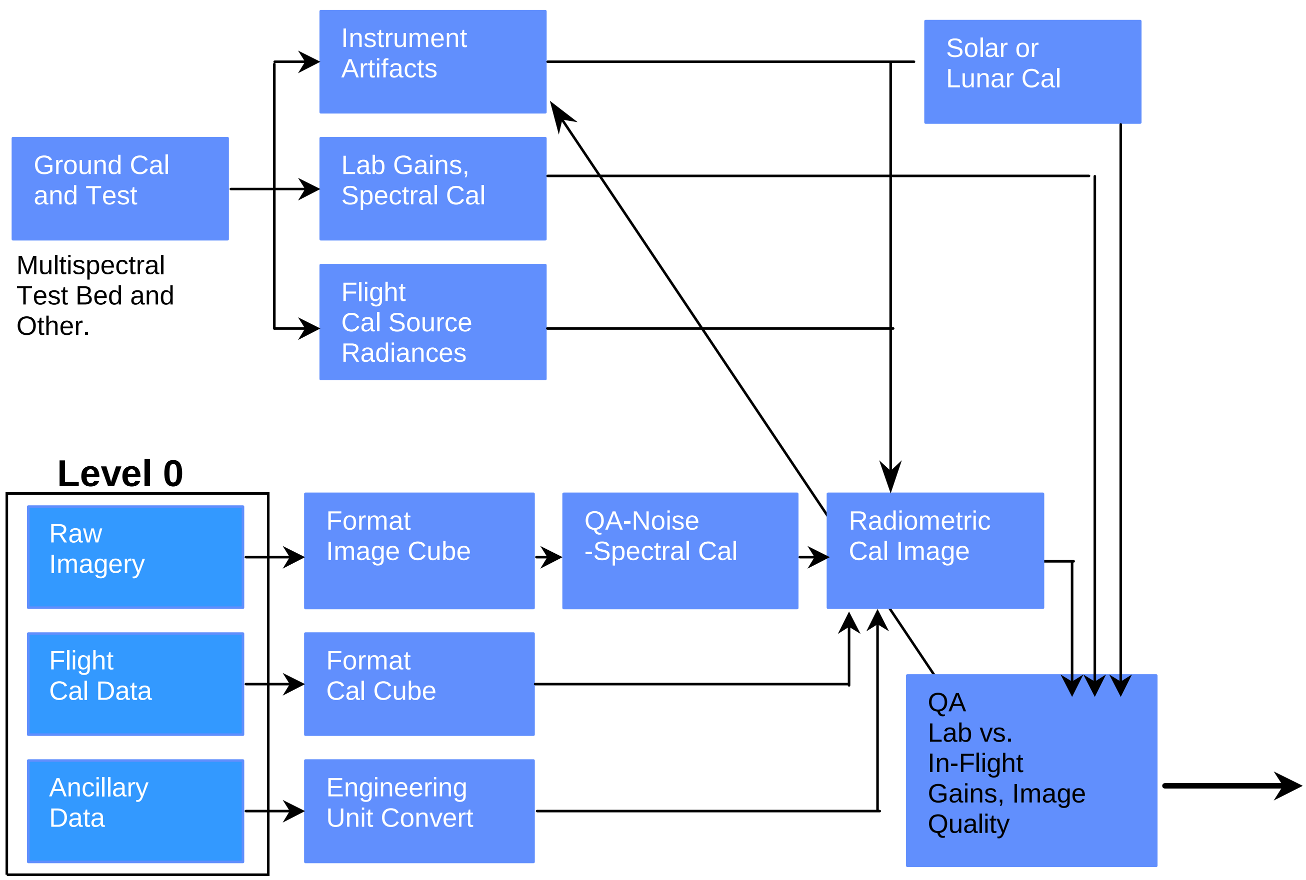


Figure 4-1 – Image data is combined with external data sets to provide a Level 1 radiometrically corrected image in HDF format.

5.0 Operations

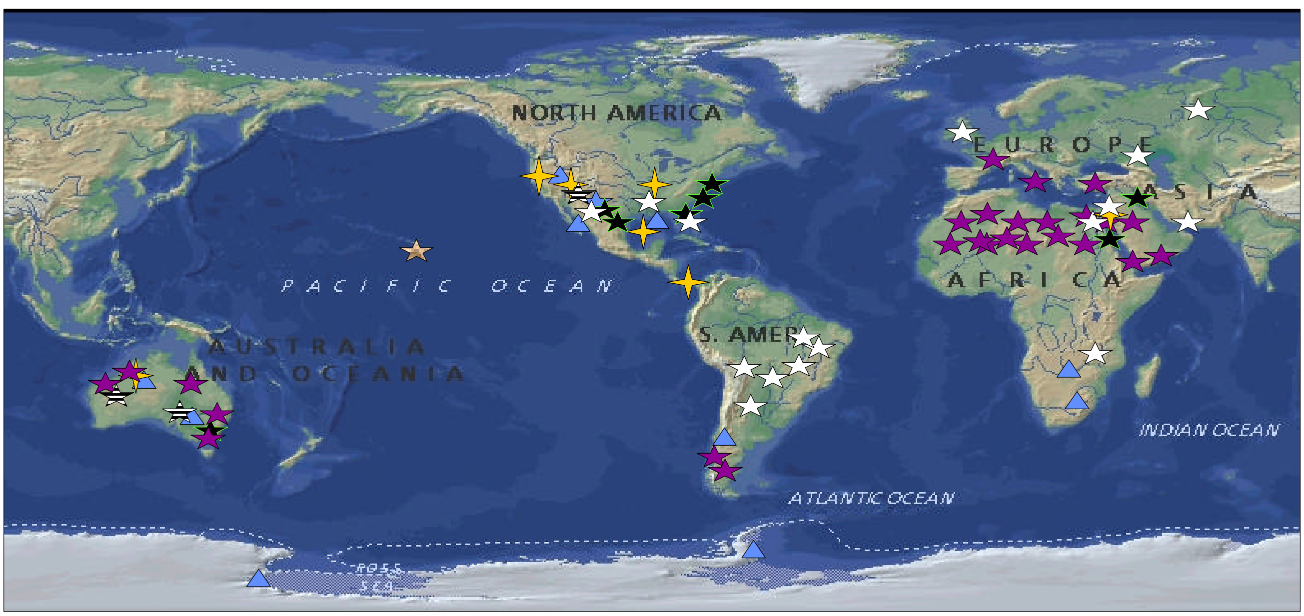
EO-1 will be placed in an orbit that provides for "formation flight" with Landsat 7, Terra and the Argentine SAC-C. The EO-1 Mission will be launched on a Delta 7320 from Vandenberg Air Force Base in late spring, 2000. EO-1 will fly in a 705km circular, sun-synchronous orbit at a 98.7 degree inclination. This orbit allows EO-1 to match the Landsat-7 orbit within one minute, and collect nearly identical images for later comparison on the ground.

EO-1 data collections will be taken on approximately four orbits per day. A data collection event (DCE) includes external image data and the internal calibrations needed to support them. The external image may be for application assessment or calibration including ground calibration, lunar calibration, or solar calibration. A typical imaging collection will include a dark calibration, an imaging data collection, a dark calibration, a light calibration and a final, dark calibration file. Lunar calibration is performed about once per month; solar calibration is performed about once per week.

Standard image sizes have been developed to facilitate data processing. For the Hyperion, an image, or cube, consists of 660 frames of data (19.8 Km long by 7.5 Km wide) and takes about 3 seconds to collect; an image equivalent to a Landsat scene is nine cubes. Data collection of longer images is possible for special requirements. The spacecraft is capable of a 22-degree roll angle that permits viewing a Landsat swath adjacent to the ground track swath. With this side-look capability, a given target on the Earth's surface can be imaged up to 5 times during the 16-day orbital ground track repeat. In this case, the angles of observation would be different because of the spacecraft roll required.

Hyperion on-orbit characterization is scheduled for the first sixty days after launch. During the first 20 days of this period, the instrument will be outgassed and activated. A calibration check will include internal lamps, solar collections and lunar imaging. Following completion of spacecraft related checkout for pointing and jitter, a full comparison with preflight baseline data will be done.

A series of calibration and reference sites in various regions of the earth will be used for the checkout. Reference sites are relatively large in area with few features, minimal vegetation, and reliably minimal cloud cover. The purpose of these sites is to provide a scene that can be imaged once or twice a month and provide a fairly constant scene over the course of a year to monitor any changes or drift in instrument performance. Nineteen reference sites have been selected in northern Africa and Australia (see Figure 5-1).



Radiometric Cal MTF, GSD Spectral Dynamic Range Geodetic Reference
Performance Assessment

Figure 5-1– Instrument Characterization Sites

In addition, several radiometric calibration sites have been selected in Australia, North America and Africa. All of these sites include some level of ground instrumentation for collecting a variety of concurrent information, including surface radiation, temperature, and atmospheric conditions. In some cases, arrangements have been made for obtaining ground truth measurements via airborne underflight coincident with satellite overflight using either the AVIRIS or Hymap instruments. Some locations, e.g., the Stennis calibration site, offer the opportunity to image a field in which an array of well-characterized radiometric materials has been deployed. Other sites have been selected for use in characterizing modulation transfer function (MTF) and ground sample distance (GSD) (e.g., include San Francisco Bay, Lake Argyle (Australia), and Iowa farm roads), stray light and dynamic range (e.g., Mauna Kea), and spectral characteristics (e.g., Mt. Fitton (Australia) and Cuprite (Nevada)).

Active calibration has been proposed to provide a precision means of measuring several instrument performance characteristics while on-orbit. Nighttime imaging of an array of xenon searchlights offers a unique opportunity for on-orbit assessment of EO-1 instrument co-alignment, MTF, GSD, spectral characteristics, stray light and radiometric calibration as well as providing data for geo-referencing. Experimental plans include deploying an array of 16 high-power (7kw each) xenon searchlights in the pattern shown in Figure 5-2. The searchlights are spaced at increasing intervals to accommodate the disparate fields-of-view and GSDs of the three EO-1 instruments. Using GPS, the searchlights can be located within 1 m of the desired position to provide geo-referencing, GSD, and geodetic information. Selection of a dry lakebed in the high desert of southern California as the deployment site provides a relatively large, flat, dark background for night imaging. The searchlights would be pointed at the satellite for nadir and off-nadir images, but no satellite tracking is planned. The spot diameter is ~21km at EO-1 orbital altitude. A metal halide spectral lamp will be used to spot check preflight laboratory spectral measurements.

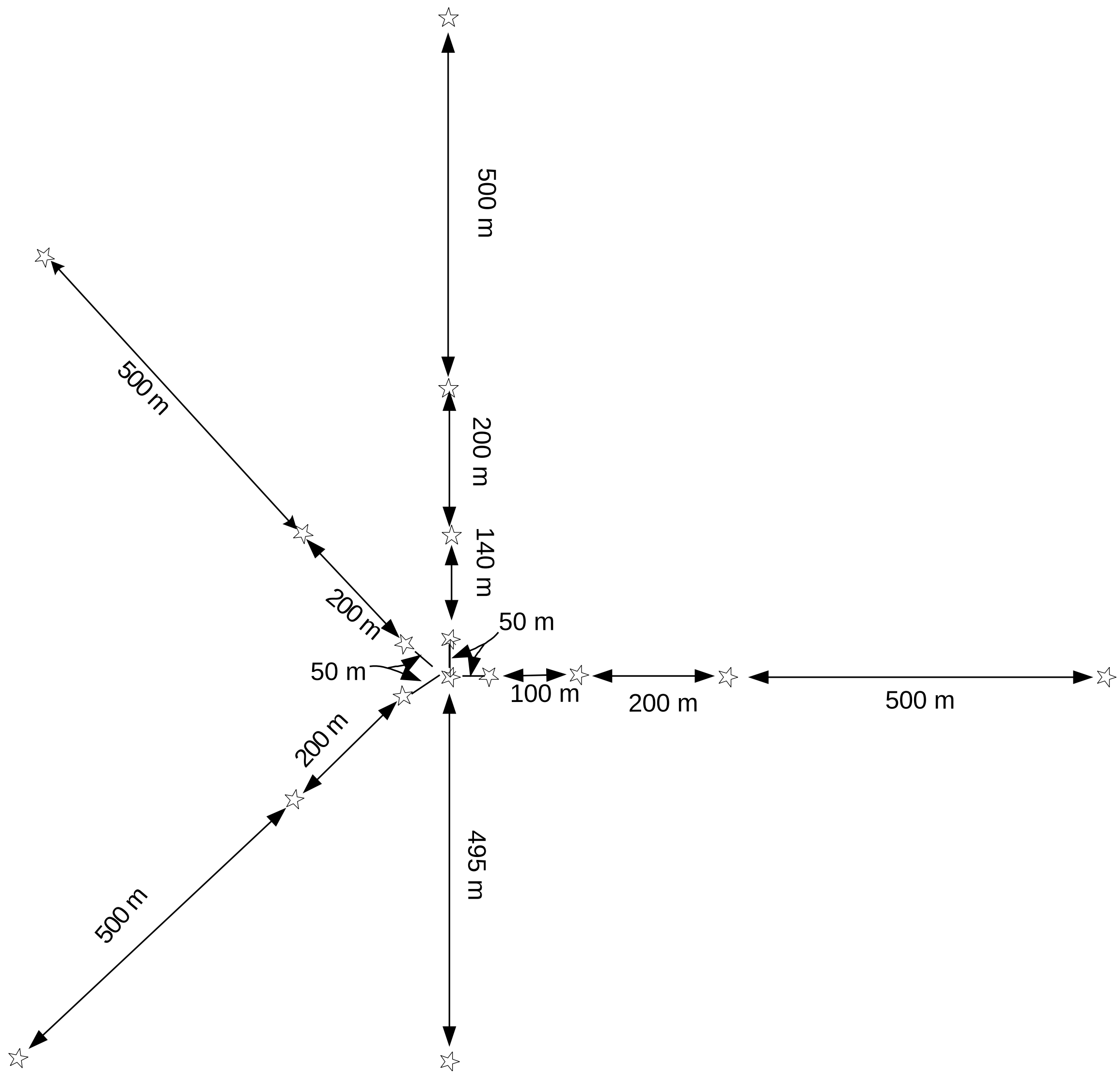


Figure 5-2 – An active calibration site using xenon searchlights has been proposed for precision, on-orbit instrument assessment

A science team has been selected by NASA to support the technology validation objectives of the EO-1 mission. This team has two objectives: first, support the calibration and further characterization of Hyperion following the on-orbit check out and second, assess the value of space-based imaging spectroscopy for earth science missions. A broad range of applications research will address the utility of hyperspectral data for assessing land cover/land use, mineral resources, coastal processes and other earth and atmospheric processes. In additions, coordination with Landsat and Terra operations will provide unique data sets for inter-comparison with ETM+, Aster, Modis and other instruments.